

United States Patent Application

for

Joint Timing Recovery for Multiple Signal Channels

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Joint Timing Recovery for Multiple Signal Channels

BACKGROUND OF THE INVENTION

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Field of the Invention

10 The invention relates generally to symbol timing recovery and more particularly to an apparatus and method for recovering a common symbol timing marker for multiple channel signals received with multiple antennas.

Description of the Prior Art

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20 When a signal is transmitted over a channel with multiple propagation paths with different delays (multipath channels), the received signal is a linearly dispersed (smeared) version of the transmitted signal. Equalization and spatial diversity are used in existing systems for reducing the distorting effects of multipath. Spatial diversity requires multiple antennas for receiving a signal through multiple signal channels. Equalization uses an equalizer to recover the original transmitted signal from its dispersed version at the receiver, in the presence of additive noise.

25 The equalizer requires an estimate of the impulse response of the channel through which the transmission took place. In packet-based systems that require fast startup, the channel estimate is typically obtained by processing a known training sequence, such as a preamble, midamble or a synch word. The channel impulse response estimate is obtained as a series of samples or "coefficients" that represent the multipath delay spread profile of the channel during a particular packet.

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Several equalizer structures exist in the art. A maximum likelihood sequence estimate (MLSE) equalizer provides optimum symbol detection. Unfortunately, the number of trellis states in an MLSE equalizer increases exponentially with the number of impulse response coefficients. Unless the packet time is accurately known and the delay spread is narrow, the complexity of the MLSE equalizer can be prohibitive.

Two other equalizer types commonly used today are the decision feedback equalization (DFE) equalizer and delayed decision feedback sequence estimation (DDFSE) equalizer. The DFE equalizer uses a feedforward filter and the DDFSE equalizer uses a Viterbi sequence estimator. However, the DFE and DDFSE equalizers are also prohibitively complex unless time is accurately known and delay spread is small because the number of taps in the feedforward filter and the number of states in the Viterbi sequence estimator increase with the number of coefficients of the channel impulse response.

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Ariyavisitakul in U.S. Patent 5,809,086 entitled "Intelligent Timing Recovery for a Broadband Adaptive Equalizer" incorporated herein by reference presents a technique for reducing the complexity of DFE or DDFSE equalizers. Unfortunately, the symbol timing recovery systems presented by Ariyavisitakul are operable only for a single signal channel. Anvari et al. in U.S. Patent 6,130,909 shows a multichannel system having equalization. However, the system shown by Anvari et al. and all others so far as is known, would be expected to suffer from poor performance if any one of the multiple channels had a low signal-to-noise. There remains a need for a symbol timing recovery system for reducing equalizer complexity in a multichannel system.

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SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a multichannel method
5 and apparatus for determining a multichannel combined symbol timing marker that
identifies an energy concentration for a combination of channel delay spreads in a
combination of signal channels in order to reduce the complexity of equalization.

Briefly, in a preferred embodiment, a multichannel signal receiver of the present
10 invention includes two or more receiver chains; a multichannel combined timer including
a multichannel combiner and a metric comparator; and a multichannel combined equalizer
for receiving wireless signals through two or more signal channels. The equalizer has a
predetermined span for equalizing the channels.

15 The receiver chains include spatially diverse antennas, signal processing circuitry,
and channel estimators. The antennas and the signal processing circuitry receive the
wireless channel signals and provide receiver chain signals. The channel estimators use
the receiver chain signals for determining channel impulse response coefficients for each
signal channel. The multichannel combiner combines energies corresponding to the
20 channel coefficients from all the channels for determining a series of multichannel
combined metrics having associated index cursors. The metric comparator determines the
largest of the metrics and issues a multichannel combined symbol timing marker for the
corresponding cursor. The symbol timing marker identifies the location in time of the
energy concentration for the delay spread for the combination of the signal channels. The
25 equalizer equalizes the combination of the channel signals jointly synchronized by the
symbol timing marker for providing equalized symbols.

These and other objects and advantages of the present invention will no doubt
become obvious to those of ordinary skill in the art after having read the following
30 detailed description of the preferred embodiments which are illustrated in the various
figures.

IN THE DRAWINGS

FIG. 1 is a block diagram of a multichannel signal receiver of the present
5 invention;

FIG. 2 is a block diagram showing multipath signals received through multiple
signal channels by multiple antennas in the receiver of FIG. 1;

10 FIG. 3 is a block diagram of an MLSE embodiment of a multichannel combiner of
the receiver of FIG. 1;

FIGS. 4A and 4B are charts showing channel impulse response coefficients for
exemplary first and second channel impulse response coefficients, respectively;
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FIG. 4C is a chart showing a multichannel combined symbol timing marker of the
present invention for the exemplary first and second channel impulse response coefficients
of FIGS. 4A and 4B;

20 FIG. 5 is a block diagram of a DFE embodiment of a multichannel combiner of the
receiver of FIG. 1;

FIG. 6 is a block diagram of a DDFSE embodiment of a multichannel combiner of
the receiver of FIG. 1; and
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FIGS. 7A-D are charts showing phases τ_0 - τ_3 , respectively, for exemplary
multichannel combined metrics for the receiver of FIG. 1.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 is a block diagram of a multichannel signal receiver of the present invention referred to by the general reference number 10. The receiver 10 includes two or more receiver chains 1, 2 through L. As described herein, structural elements of the receiver chains 1, 2 through L are referenced with subscripts "1", "2" through "L", respectively. It should be noted that the present invention can be used with any number of channels and receiver chains equal to or greater than two.

The receiver chains 1, 2 through L include antennas A_1, A_2 through A_L , respectively, having different spatial positions (spatial diversity). Referring to FIG. 2, a transmitter 12 transmits a wireless transmitted signal that passes through channels CH_1, CH_2 through CH_L to be received as wireless channel signals S_{CH1}, S_{CH2} through S_{CHL} by the antennas A_1, A_2 through A_L , respectively. In general, each of the channel signals S_{CH1}, S_{CH2} through S_{CHL} is composed of several signals traveling different geometric paths (multipath) due to reflections. Because the antennas A_1, A_2 through A_L have different spatial positions, the multipath fading experienced by one of the antennas A_1, A_2 through A_L will not necessarily be experienced by the other antennas A_1, A_2 through A_L .

Returning to FIG. 1, the receiver chains 1, 2 through L include analog circuitry, denoted G_1, G_2 through G_L , analog-to-digital converters, denoted $A/D_1, A/D_2$ through A/D_L , and digital circuitry, denoted g_1, g_2 through g_L . The antennas A_1, A_2 through A_L convert the RF wireless signals S_{CH1}, S_{CH2} through S_{CHL} into RF conducted signals and pass the RF conducted signals to the analog circuitry G_1, G_2 through G_L . The analog circuitry G_1, G_2 through G_L amplifies, filters and frequency downconverts the RF conducted output signals to intermediate signals and pass the intermediate signals to the analog-to-digital converters $A/D_1, A/D_2$ through A/D_L . The analog-to-digital converters $A/D_1, A/D_2$ through A/D_L convert the intermediate signals from an analog format to a digital format and pass the digital format signals to the digital circuitry g_1, g_2 through g_L . Preferably, there are several analog-to-digital converters $A/D_1, A/D_2$ through A/D_L .

operating in parallel sampled at two or more offset phases τ for providing parallel digital signals at the phases τ . The digital circuitry g_1, g_2 through g_L amplifies, level shifts, filters and/or frequency converts the digital signals for providing receiver chain signals $r_{1,n}(\tau)$, $r_{2,n}(\tau)$ through $r_{L,n}(\tau)$, respectively, as shown in an equation 1, below.

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$$r_{l,n}(\tau) = \sum_{k=-K_1}^{K_2} x_{n-k} h_{l,k}(\tau) + \eta_{l,n}, k = -K_1 \text{ to } K_2 \quad (1)$$

In the equation 1, the $r_{l,n}(\tau) = r_l(nT+\tau)$ is the receiver chain signal for the l th receiver chain at a receiver chain index n corresponding to a time $nT+\tau$ where the τ denotes the phase and the T is the symbol period. The $x_{n-k} = x_m$ is the m th symbol in the transmitted signal from the transmitter 12 (FIG. 2). The $h_{l,k}(\tau) = h_l(kT+\tau)$ are the channel impulse response coefficients for the l th channel (CH₁, CH₂ through CH_L) at channel impulse response indexes k where k takes on values from a first channel impulse response index $-K_1$ to a last channel impulse index $+K_2$. The channels CH₁, CH₂ through CH_L are assumed to have channel impulse response coefficients of zero, $h_{l,k}(\tau) = 0$, for k less than the first channel index $-K_1$ or greater than the last channel index $+K_2$. The $\eta_{l,n}$ is the noise on the l th receiver chain signal at the n th receiver chain index.

The receiver 10 includes a multichannel combined timer 18 including a multichannel combiner 20 and a metric comparator 22. The multichannel combiner 20 blends the channel impulse response coefficients from all receiver chains 1, 2 through L for determining a series of multichannel combined metrics and the metric comparator 22 determines a multichannel combined symbol timing marker S_C (FIG. 4C) as described in the detailed descriptions below from the largest of the multichannel combined metrics.

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The receiver 10 also includes an equalizer 23, channel estimators 24₁, 24₂ through 24_L, data buffers 26₁, 26₂ through 26_L, channel buffers 28₁, 28₂ through 28_L; and optional receiver chain noise estimators 34₁, 34₂ through 34_L. The channel estimators 24₁, 24₂ through 24_L estimate sets of the channel impulse response coefficients $h_{1,k}(\tau)$, $h_{2,k}(\tau)$

through $h_{L,k}(\tau)$ according to the equation 1 by correlating the receiver chain signals $r_{1,n}(\tau)$, $r_{2,n}(\tau)$ through $r_{L,n}(\tau)$ against a known training sequence for the transmitted symbols x_m . The data buffers 26₁, 26₂ through 26_L use the symbol timing marker S_C (FIG. 4C) to synchronize the receiver chain signals $r_{1,n}(\tau)$, $r_{2,n}(\tau)$ through $r_{L,n}(\tau)$ to the incoming symbols for providing synchronized receiver chain signals DATA₁, DATA₂ through DATA_L, respectively, to the equalizer 23.

The channel buffers 28₁, 28₂ through 28_L provide synchronized channel signals CHAN₁, CHAN₂ through CHAN_L, respectively, which are a subset of the channel coefficients $h_{1,k}(\tau)$, $h_{2,k}(\tau)$ through $h_{L,k}(\tau)$, $k = -K_1$ to K_2 . The length of each of the CHAN_{1-L} is equal to an equalizer span W . The first index k of the equalizer span W is identified by the symbol timing marker S_C . The equalizer 23 uses the synchronized channel signals CHAN₁, CHAN₂ through CHAN_L for the symbol timing marker S_C (FIG. 4C) and the equalizer index span W for equalizing the synchronized receiver chain signals DATA₁, DATA₂ through DATA_L in order to provide equalized symbols. For example, when the symbol timing marker S_C corresponds to a channel index $k = 10$ and the equalizer span W is 6, the equalizer 23 uses the channel coefficients $h_{1,k}(\tau)$, $h_{2,k}(\tau)$ through $h_{L,k}(\tau)$ for the impulse response indexes 10, 11, 12, 13, 14 and 15 with the DATA_{1-L} signals corresponding to the marker S_C for providing the equalized symbols.

For optimum performance, the noise estimators 34₁, 34₂ through 34_L determine receiver chain noise levels p_1 , p_2 through p_L (corresponding to $\eta_{l,n}$ in the equation 1) for the receiver chain signals $r_{1,n}(\tau)$, $r_{2,n}(\tau)$ through $r_{L,n}(\tau)$, respectively. The noise levels p_1 , p_2 through p_L can be determined from a received signal strength indication (RSSI) measurement or by using a first estimate of the symbol timing marker S_C . The noise levels p_1 , p_2 through p_L can also be determined in an iterative approach using the equation 1 from the symbols in the receiver chain signals $r_{1,n}(\tau)$, $r_{2,n}(\tau)$ through $r_{L,n}(\tau)$. In the iterative approach either the symbol timing marker S_C or the noises levels p_1 , p_2 through p_L are estimated first. Then the estimate of the symbol timing marker S_C (or the noise levels p_1 , p_2 through p_L) is used to determining the noise levels p_1 , p_2 through p_L (or symbol timing marker S_C) and the determinations of the noise levels p_1 , p_2 through p_L (or

symbol timing marker S_C) are used to refine the estimate of the symbol timing marker S_C (or noise levels p_1, p_2 through p_L) and so on.

5 The noise levels p_1, p_2 through p_L are used in the multichannel combiner 20 for scaling the energies of the channel impulse responses $h_{1,k}(\tau)$, $h_{2,k}(\tau)$ through $h_{L,k}(\tau)$ by receiver chain scale factors $1/p_1, 1/p_2$ through $1/p_L$, respectively. However, empirical results show that this scaling is not necessary for some systems and that good results may be obtained using equally weighted channel impulse response energies $|h_{1,k}(\tau)|^2, |h_{2,k}(\tau)|^2$ through $|h_{L,k}(\tau)|^2$. The scale factors may or may not be a constant and may or may not be
10 the same for all channel impulse response energies $|h_{1,k}(\tau)|^2, |h_{2,k}(\tau)|^2$ through $|h_{L,k}(\tau)|^2$ depending upon the system.

The channel impulse response coefficients $h_{1,k}(\tau)$, $h_{2,k}(\tau)$ through $h_{L,k}(\tau)$ and optionally the noise levels p_1, p_2 through p_L or other scale factors are received by the
15 multichannel combiner 20. The multichannel combiner 20 combines the energies of the channel impulse response coefficients $h_{1,k}(\tau)$, $h_{2,k}(\tau)$ through $h_{L,k}(\tau)$ for predetermined channel indexes k into multichannel combined metrics having associated index cursors c (and phases τ). The range of the channel indexes k and the combining algorithms (EQS. 2-4) depend upon the type of equalizer 23. Successive multichannel combined metrics are
20 computed for successive cursors c starting at the cursor c at the first channel index ($-K_1$) and ending with the cursor c at the equalizer span W less than the last channel index ($K_2 - W$). The metric comparator 22 determines the largest of the multichannel combined metrics and designates the cursor c (and the phase τ) associated with the largest multichannel combined metric as the symbol timing marker S_C (FIG. 4C).

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There are several types of equalizers that can be used for the equalizer 23. Three of these types of the equalizer 23 are known in general terms as a maximum likelihood sequence estimator (MLSE) equalizer, a decision feedback equalization (DFE) equalizer, and a decision feedback sequence estimation (DDFSE) equalizer. The multichannel
30 combiner 20 has embodiments 20A, 20B and 20C for use with the MLSE, DFE and DDFSE embodiments, respectively, of the equalizer 23.

FIG. 3 is a block diagram of an MLSE embodiment of the multichannel combiner 20 referred to with the reference designator 20A. The MLSE multichannel combiner 20A computes a series of multichannel combined metrics, denoted as $\alpha(c, \tau)$, according to an equation 2, below.

$$\alpha(c, \tau) = \sum_l \frac{1}{p_l} \sum_{k=c}^{c+W} |h_{l,k}(\tau)|^2, c = -K_1, \dots, K_2 - W \quad (2)$$

As shown in the equation 2, the multichannel combiner 20A determines the series of multichannel combined metrics $\alpha(c, \tau)$ by combining the channel (impulse) response energies $1/p_1 |h_{1,k}(\tau)|^2$, $1/p_2 |h_{2,k}(\tau)|^2$ through $1/p_L |h_{L,k}(\tau)|^2$ for index k ranges equal to the equalizer index span W starting at index cursors c for the series of the index cursors c , respectively. The series of the cursors c takes on indexes from the first channel index $-K_1$ to the span W less than the last channel index $+K_2$. The metric comparator 22 determines the largest of the multichannel combined metrics $\alpha(c, \tau)$ and then uses the cursor c and phase τ (FIGS. 7A-D) of the argument (c, τ) of the largest of the multichannel combined metrics $\alpha(c, \tau)$ for the symbol timing marker S_C .

The multichannel combiner 20A in a preferred embodiment includes a multichannel sliding span combiner 42 and functional elements, denoted as squarers 45₁, 45₂ through 45_L for deriving channel response energies $|h_{1,k}(\tau)|^2$, $|h_{2,k}(\tau)|^2$ through $|h_{L,k}(\tau)|^2$ from the channel impulse response coefficients $h_{1,k}(\tau)$, $h_{2,k}(\tau)$ through $h_{L,k}(\tau)$, respectively. Optionally, the MLSE multichannel combiner 20A also includes functional elements, denoted as scalars 46₁, 46₂ through 46_L for scaling the channel response energies $|h_{1,k}(\tau)|^2$, $|h_{2,k}(\tau)|^2$ through $|h_{L,k}(\tau)|^2$ by the receiver chain scale factors $1/p_1$, $1/p_2$ through $1/p_L$. The multichannel sliding span combiner 42 adds the index range of the channel response energies $1/p_1 |h_{1,k}(\tau)|^2$, $1/p_2 |h_{2,k}(\tau)|^2$ through $1/p_L |h_{L,k}(\tau)|^2$ for the equalizer index span W for the successive cursors c from $-K_1$ to $+K_2 - W$ for providing the multichannel combined metrics $\alpha(c, \tau)$.

FIGS. 4A and 4B illustrate an exemplary case having first and second channel impulse response coefficients $h_{1,k}(\tau_0)$ and $h_{2,k}(\tau_0)$, respectively, for the channel index k from a first index 0 ($-K_1$) to a last index 22 ($+K_2$) and a phase $\tau = \tau_0$. The dotted lines 48₁ and 48₂ represent envelopes of the channel impulse response coefficients $h_{1,k}(\tau_0)$ and $h_{2,k}(\tau_0)$, respectively, and the vertical solid lines 49₁ and 49₂ represent the channel impulse response coefficients $h_{1,k}(\tau_0)$ and $h_{2,k}(\tau_0)$, respectively, at the channel indexes k . The span W of the equalizer 23 is shown as six of the channel indexes k . The cursor c has a range of channel indexes k from $-K_1$ to $+K_2 - W$.

In the exemplary case, it can be seen by inspection that the channel impulse response coefficients $h_{1,k}(\tau_0)$ have an equalizer span W concentration of energy indicated by a symbol timing marker S_1 corresponding to the cursor c that in turn corresponds to the channel index $k = 9$ (moving S_1 by one channel index k in either direction will decrease the sum of the first channel response energies $|h_{1,k}(\tau_0)|^2$ in the span W). Similarly, for the second channel response coefficients $h_{2,k}(\tau_0)$ it can be seen by inspection that the symbol timing marker S_2 for the equalizer span W concentration of energy corresponds to the cursor c that corresponds to the channel index $k = 15$ (moving S_2 by one channel index k in either direction will decrease the sum of the second channel response energies $|h_{2,k}(\tau_0)|^2$ in the span W).

FIG. 4C shows the results of calculations in the exemplary case according to the equation 2 for the multichannel combined metrics $\alpha(c, \tau)$ for the MLSE embodiment 20A (FIG. 3) for the cursors c from $-K_1$ to $+K_2 - W$. The vertical bars 50 represent the energy levels of the multichannel combined metrics $\alpha(c, \tau)$ for the cursors c from $-K_1$ to $+K_2 - W$. The multichannel symbol timing marker S_C indicates the cursor c corresponding to the channel index $k = 10$ for the largest of the multichannel combined metrics $\alpha(c, \tau)$ for the equalizer span W concentration of energy for the multichannel signal receiver 10 of the present invention. It should be noted that the joint symbol timing marker S_C of the present invention is not equal to either of the individual markers S_1 or S_2 , or to their average.

More generally, there is no way to derive the joint symbol timing marker S_c from the knowledge of S_1 and S_2 alone, other than using the joint timing recovery methods of the present invention.

5 FIG. 5 is a block diagram of an DFE embodiment of the multichannel combiner 20 referred to with the reference designator 20B. The DFE multichannel combiner 20B computes a series of multichannel combined metrics, denoted as $\beta(c, \tau)$, according to an equation 3, below.

$$10 \quad \beta(c, \tau) = \frac{\sum_l \frac{1}{p_l} |h_{l,c}(\tau)|^2}{\sum_l \left(\frac{1}{p_l} \sum_{k=-K_1}^{c-1} |h_{l,k}(\tau)|^2 \right) + N_0}, c = -K_1, \dots, K_2 - W \quad (3)$$

As shown in the equation 3, the multichannel combiner 20B determines the series of multichannel combined metrics $\beta(c, \tau)$ by inversely scaling (deemphasizing) a sum of the channel response energies $1/p_1 |h_{1,c}(\tau)|^2$, $1/p_2 |h_{2,c}(\tau)|^2$ through $1/p_L |h_{L,c}(\tau)|^2$ corresponding to a particular one of the index cursors c by a sum of an initial precursor term N_0 plus a sum of the channel response energies $1/p_1 |h_{1,k}(\tau)|^2$, $1/p_2 |h_{2,k}(\tau)|^2$ through $1/p_L |h_{L,k}(\tau)|^2$ for the index k ranges from the first index $-K_1$ to one less than the particular index cursor c , for the series of the index cursors c , respectively. The series of the cursors c takes on indexes from the first channel index $-K_1$ to the equalizer span W less than the last channel index $+K_2$. When the optional noise scale factors $1/p_1$, $1/p_2$ through $1/p_L$ are used, the initial precursor term N_0 may be set to one. When the optional noise scale factors $1/p_1$, $1/p_2$ through $1/p_L$ are not used, the initial precursor term N_0 should be set to some function of the noise levels p_1, p_2 through p_L , preferably the lowest of the noise levels p_1, p_2 through p_L .

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For example when the current cursor $c = -K_1$, the multichannel combined metric $\beta(c, \tau)$ is the sum of the channel response energies $\frac{1}{p_1} |h_{1,-K_1}(\tau)|^2 + \frac{1}{p_2} |h_{2,-K_1}(\tau)|^2$

through $+ \frac{1}{p_L} |h_{L,-K_1}(\tau)|^2$ divided by $1/N_0$. When the cursor $c = -K_1 + 1$, the multichannel combined metric $\beta(c, \tau)$ is the sum of the channel response energies $\frac{1}{p_1} |h_{1,-K_1+1}(\tau)|^2$
 $+ \frac{1}{p_2} |h_{2,-K_1+1}(\tau)|^2$ through $+ \frac{1}{p_L} |h_{L,-K_1+1}(\tau)|^2$ divided by the sum of the initial precursor term N_0 plus the channel response energies $\frac{1}{p_1} |h_{1,-K_1+1}(\tau)|^2 + \frac{1}{p_2} |h_{2,-K_1+1}(\tau)|^2$ through
5 $+ \frac{1}{p_L} |h_{L,-K_1+1}(\tau)|^2$. When the cursor $c = -K_1 + 2$, the multichannel combined metric $\beta(c, \tau)$ is the sum of the channel response energies $\frac{1}{p_1} |h_{1,-K_1+2}(\tau)|^2 + \frac{1}{p_2} |h_{2,-K_1+2}(\tau)|^2$
through $+ \frac{1}{p_L} |h_{L,-K_1+2}(\tau)|^2$ divided by the sum of the initial precursor term N_0 plus
 $\frac{1}{p_1} |h_{1,-K_1+1}(\tau)|^2 + \frac{1}{p_2} |h_{2,-K_1+1}(\tau)|^2$ through $+ \frac{1}{p_L} |h_{L,-K_1+1}(\tau)|^2$ plus $\frac{1}{p_1} |h_{1,-K_1+2}(\tau)|^2$
 $+ \frac{1}{p_2} |h_{2,-K_1+2}(\tau)|^2$ through $+ \frac{1}{p_L} |h_{L,-K_1+2}(\tau)|^2$. The example may be continued on in the
10 same way for the cursor c from $-K_1 + 2$ to $+K_2 - W$.

In a preferred embodiment the DFE multichannel combiner 20B includes a multichannel deemphasizer 52 and a multichannel precursor calculator 54. The DFE multichannel combiner 20B also includes the functional squarers 45₁, 45₂ through 45_L and
15 optionally the functional scalars 46₁, 46₂ through 46_L operating as described above. The multichannel deemphasizer 52 includes a multichannel sliding combiner 56 and a scaler 58.

The multichannel precursor calculator 54 sums the initial precursor term N_0 and
20 the channel response energies $1/p_1 |h_{1,k}(\tau)|^2$, $1/p_2 |h_{2,k}(\tau)|^2$ through $1/p_L |h_{L,k}(\tau)|^2$ over a range of the channel indexes k from $-K_1$ to the channel index k one less than the cursor c for the series of cursors c from $-K_1$ to $K_2 - W$ for determining a series of precursor deemphasis coefficients. When the cursor $c = -K_1$, the precursor deemphasis coefficient is N_0 . The multichannel sliding combiner 56 sums the channel response energies $1/p_1$

$|h_{1,c}(\tau)|^2$, $1/p_2 |h_{2,c}(\tau)|^2$ through $1/p_L |h_{L,c}(\tau)|^2$ for the cursor c for providing a series of multichannel single index sums for the series of cursors c from $-K_1$ to $K_2 - W$. The scaler 58 deemphasizes (inversely scales) the series of multichannel single index sums by the series of precursor deemphasis coefficients, respectively, for providing the series of

5 multichannel combined metrics $\beta(c, \tau)$. The metric comparator 22 determines the largest one of the multichannel combined metrics $\beta(c, \tau)$ and then uses the argument (c, τ) of the largest of the multichannel combined metrics $\beta(c, \tau)$ for the symbol timing marker S_C .

FIG. 6 is a block diagram of an DDFSE embodiment of the multichannel combiner

10 20 referred to with the reference designator 20C. The DDFSE multichannel combiner 20C computes a series of multichannel combined metrics, denoted as $\chi(c, \tau)$, according to an equation 4, below.

$$\chi(c, \tau) = \frac{\sum_l \frac{1}{p_l} \sum_{k=c}^{c+W} |h_{l,k}(\tau)|^2}{\sum_l \left(\frac{1}{p_l} \sum_{k=-K_1}^{c-1} |h_{l,k}(\tau)|^2 \right) + N_0}, c = -K_1, \dots, K_2 - W \quad (4)$$

15 As shown in the equation 4, the multichannel combiner determines the series of multichannel combined metrics $\chi(c, \tau)$ by inversely scaling (deemphasizing) a sum of the channel (impulse) response energies $1/p_1 |h_{1,k}(\tau)|^2$, $1/p_2 |h_{2,k}(\tau)|^2$ through $1/p_L |h_{L,k}(\tau)|^2$ for index k ranges equal to the equalizer span W starting at particular index cursors c with a

20 sum of the initial precursor term N_0 plus a sum of the channel response energies $1/p_1 |h_{1,k}(\tau)|^2$, $1/p_2 |h_{2,k}(\tau)|^2$ through $1/p_L |h_{L,k}(\tau)|^2$ for the index k ranges from the first index $-K_1$ to one less than the particular index cursors c , . The series of the cursors c takes on indexes from the first channel index $-K_1$ to the equalizer span W less than the last channel index $+K_2$.

25 In a preferred embodiment the DDFSE multichannel combiner 20C includes a multichannel span deemphasizer 62; and the multichannel precursor calculator 54, the functional squarers 45₁, 45₂ through 45_L, and optionally the functional scalers 46₁, 46₂

through 46_L operating as described above. The multichannel span deemphasizer 62 includes the multichannel sliding span combiner 42 and the scaler 58 operating as described above using the precursor deemphasis coefficients and the channel response energies $1/p_1 |h_{1,k}(\tau)|^2$, $1/p_2 |h_{2,k}(\tau)|^2$ through $1/p_L |h_{L,k}(\tau)|^2$ for providing the series of channel combined metrics $\chi(c, \tau)$. The metric comparator 22 determines the largest of the multichannel combined metrics $\chi(c, \tau)$ and then uses the argument (c, τ) of the largest of the multichannel combined $\chi(c, \tau)$ for the symbol timing marker S_C.

FIGS. 7A, B, C, and D illustrate the phases τ of the channel index k at phase τ_0 , phase τ_1 , phase τ_2 , and phase τ_3 , respectively, the multichannel combined metrics $\alpha(c, \tau)$, $\beta(c, \tau)$ or $\chi(c, \tau)$. An envelope of the multichannel combined metrics $\alpha(c, \tau)$, $\beta(c, \tau)$ or $\chi(c, \tau)$ between the channel indexes $k=6$ and $k=7$ is shown as a dotted line 64_C. The phases τ for more than one sample per symbol time period may be used for providing for providing phased channel impulse response indexes k, τ . Where the phases τ are used, the multichannel combiner 20 computes phased multichannel combined metrics for each of the cursors c for each of the phases τ . The metric comparator 22 determines the largest of the phased multichannel combined metrics and determines the symbol timing index S_C from the associated cursor c and the phase τ of the largest phased multichannel combined metric.

Although the present invention has been described in terms of the presently preferred embodiments, it is to be understood that such disclosure is not to be interpreted as limiting. Various alterations and modifications will no doubt become apparent to those skilled in the art after having read the above disclosure. Accordingly, it is intended that the appended claims be interpreted as covering all alterations and /modifications as fall within the true spirit and scope of the invention. What is claimed is: